

A Grid-Connected Hybrid PV/Wind/Fuel-Cell System with Battery Energy Storage: An Innovative Method for Managing Solar PV Without Converters

K. Jyothi¹, A. Jyothiramai²

¹Electrical and Electronics Engineering & Holy Mary Institute of Technology Science

²Electrical and Electronics Engineering & Holy Mary Institute of Technology Science

Abstract - The suggested initiative seeks to design, control, administer, and function a hybrid grid-connected framework that includes wind energy, solar photovoltaics, fuel cells, electrolyzers, and a battery energy storage system. A hybrid photovoltaic-wind-fuel cell system with a battery energy storage system as an electrolyser and minimal control loops and converters is shown. The suggested hybrid system offers a more economical method for incorporating photovoltaic technology by eliminating the need for a PV converter. It involves the formulation of controllers for hybrid systems linked to the grid. In several systems, the principal source is the renewable distributed generator (wind, photovoltaic), the secondary source is the battery energy storage system (BESS), and the tertiary source is the fuel cell with electrolyser. The integrator and lead compensator are employed to attain a substantial phase margin and completely eradicate the steady-state error. A phase shift ϕ_s at the cross-gain frequency ω_{cut} is implemented to enhance the controller's stability. The Grid Side Controller (GSC) interfaces with the utility grid and is capable of providing frequency assistance. The optimal photovoltaic power contribution to the grid via the GSC is achieved with the suggested configuration. The GSC and Rotor Side Converter (RSC) enable the distribution of load at the grid station. In addition, the suggested BESS controller operating in conjunction with FC mitigates the impact of the variable characteristics of the energy supplied by PV and wind. The electrolyser utilises surplus power produced by decentralised renewable energy sources to manufacture hydrogen. During inclement weather, when electricity production ceases, the fuel cell utilises this hydrogen.

KeyWords: Grid-connected system, energy management system, battery energy storage system, electrolyzer, fuel cell, doubly fed induction motor, maximum power point tracking.

1.INTRODUCTION

The extensive accessibility of domestic gadgets designed for doing everyday household chores has markedly enhanced individuals' quality of life. Nonetheless, as an increasing number of household devices connect to the power grid, the need for electricity is escalating. Electricity production is consistently rising in response to the demand for power. To satisfy the demand, the electrical grid is expanded to incorporate both renewable and non-renewable energy sources. The necessity to accommodate a diverse array of both conventional and unconventional sources affects the design of power flow. In light of escalating environmental apprehensions in recent decades, governments are striving

to integrate renewable energy into the national system to fulfil the total electricity demand. The current energy generation framework employs renewable resources such as photovoltaics (PV), fuel cells (FC), ultracapacitors (US), water thermal (WT), geothermal (HT), among others, to generate clean and sustainable energy. Wind turbines and solar cells are among the most favoured renewable energy sources as they produce electricity without requiring fuel, facilitating easy installation and offering an advantageous cost-to-power ratio. Worldwide, various classifications utilise these two types of generators [3,4],[5]. Wind turbines serve as a dependable electricity source due to their ability to regulate their own power generation. The architectural research community dedicated to wind turbine production is presently concentrating on offshore topological wind turbines. Wind turbine velocity regulation is employed by doubly fed induction generators (DFIGs), which serve as a highly efficient power generation resource. The rotor velocity can be modified in relation to wind velocity to guarantee optimal power point tracking (MPPT) of the energy generated by the turbine [6]. In the past few decades, various control methodologies have been suggested by scholars to enhance the efficiency of DFIG power generation turbines [7, 8, 9, 10, 11]. Liu et al. [10] and Xu et al. [11] have employed various sophisticated control techniques to mitigate transient oscillations transmitted to the stator from the rotor side as a result of fluctuations in wind velocity. To reduce harmonics in current and voltage, Nian and Song [12] proposed a voltage conditioning framework for DFIG power generation that stabilises both active and reactive power production together with their transitions. In contrast to wind energy, a solar system provides a reliable and manageable means of generating electricity. They do not produce adverse impacts such as air contamination, auditory disturbances, or mechanical degradation like wind turbines do. Numerous megawatts of solar farms have recently been established to satisfy the increasing electricity demand. The two primary topologies employed to incorporate the electric power from the PV array into the grid are one-stage and two-stage systems. Single-stage integration topologies consist of a reduced number of converters and power switches compared to two-stage configurations, although the control architecture facilitating their operation is more sophisticated. The Voltage Source Inverter (VSI) technique is commonly employed to regulate the infusion of power into the grid.

2. Combined Photovoltaic/Wind/Fuel Cell Grid-Linked System

Grid-tied hybrid photovoltaic/wind/fuel cell systems are a type of renewable energy generation that employs power electronic converters to connect with the utility grid. These systems integrate fuel cell technology, solar photovoltaic (PV) systems, and wind energy. The primary aim is to amalgamate the benefits of renewable energy sources, including solar, wind, and fuel cells, to enhance the reliability and stability of the power supply. Solar and wind energy serve as instances of sporadic renewable energy sources. Wind energy production is affected by wind velocity, whereas photovoltaic energy output is chiefly determined by temperature and solar irradiance. Conversely, a fuel cell can supply consistent electricity when renewable energy sources fall short. A composite system that integrates all three of these sources is superior in:

Section 2.1: The Suggested Grid-Integrated Hybrid System

The configuration of the suggested system is illustrated in Fig. 1. The suggested solution employs the GSC and its regulation method to keep the DC-bus voltage within the specified safe thresholds. The system can further observe the MPP of the PV system due to the DC-link voltage. When utilised with the system, a BESS protects the GSC from excess loads. The BESS, a storage apparatus, interfaces with the DC bus using a bidirectional DC/DC Buck Boost converter. The climate influences both wind and solar energy, however photovoltaic production ceases completely at sunset. Consequently, the battery by itself cannot fulfil the complete load demand when both wind and photovoltaic energy are either lacking or inadequate. To enhance the sustainability of the system, FC is incorporated with electrolysis. The battery will possess sufficient energy reserves to initiate the electrolysis process and retain any surplus energy when wind and solar power production attains a specific level. The electrolysis generates hydrogen, which fuel cells can retain and utilise as a feedstock. FC utilises hydrogen as an energy source when adverse weather conditions hinder the DC link from generating sufficient electricity.

3. System Simulation and Regulation
A. Advancement of Solar Photovoltaic Frameworks
Upon illumination, the multitude of discrete solar cells constituting photovoltaic (PV) arrays generate charge carriers. When photon energy exceeds the band gap, electrons are liberated, resulting in current flow within a semiconductor. Numerous cost-effective and efficient polycrystalline solar cells exist alongside the more widely recognised monocrystalline variants. Identifying the appropriate solar equation that correlates with actual behaviour has been the focus of considerable investigation to date. The attributes of solar cells utilised in arrays are unfavourable. A contemporary current source along with several interconnected diodes would constitute the ideal photovoltaic array. The schematic for an individual solar cell is seen in Figure 1, with a Shockley

diode, a current source, and both parallel and series resistances R_{per} and R_{ser} . The overall current of the solar cell is dictated by the aggregate of the currents flowing through the diode and the current source [51]. The proposed hybrid system framework employs voltage-flux equations within the d-q reference frame to regulate the DFIG [52]. This hypothesis posits that the stator flux space vector and the d-axis of the reference frame are completely aligned at the synchronous speed of the stator. The formula pertaining to the rotor and stator that addresses the rotor current components is shown in equation (6)

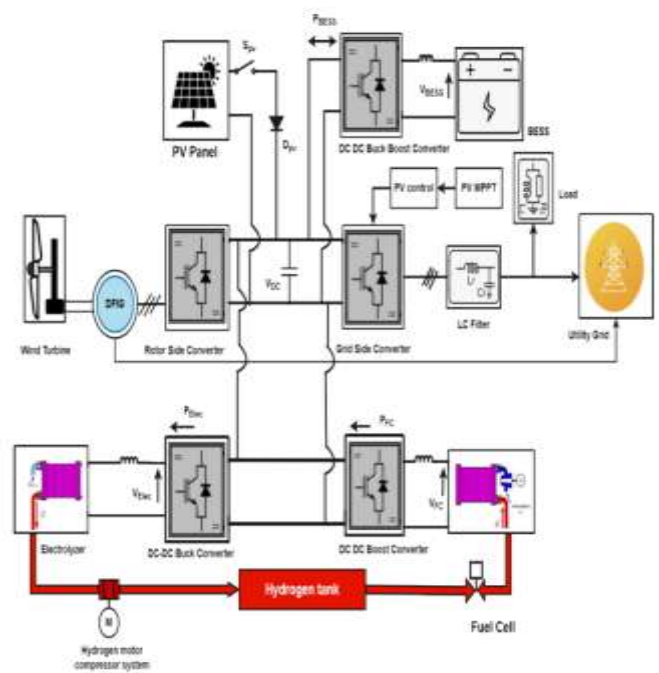


Fig 1. Structure of proposed grid connected hybrid system.

4.SIMULATION RESULTS

The WTG-DFIG, photovoltaic, and battery energy storage systems integrated within a hybrid grid framework in this study have incorporated the fuel cell and electrolyser. The MATLAB Simulink platform is employed to regulate the power of the planned system, and the hybrid grid-connected system is presently functioning. We modelled the complete system under various loads and environmental conditions. The implications of this hybrid system on the efficacy and calibre of the injected and/or required energy are emphasised

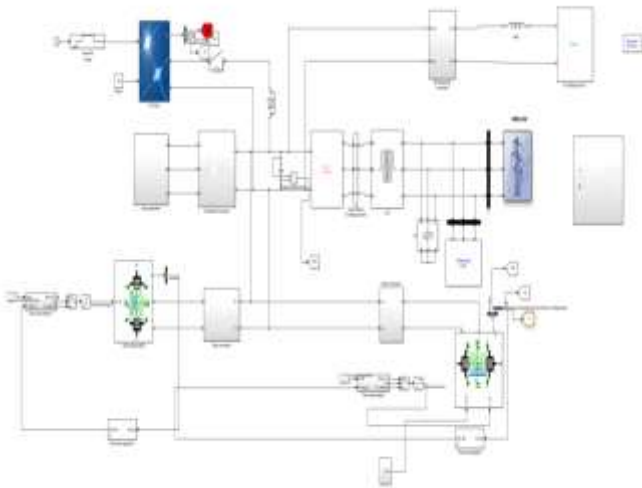


Fig 2. simulation diagram

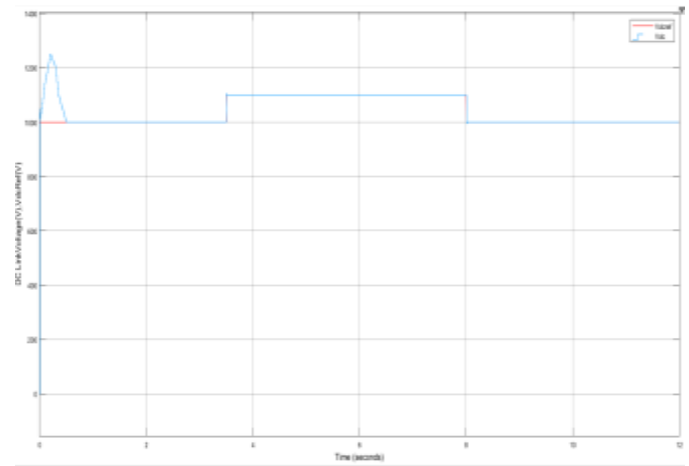


Fig.5. DC Link Voltage

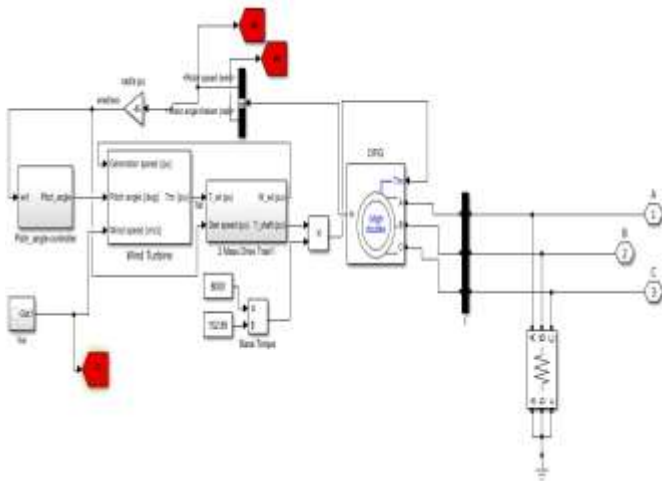


Fig.3.. Simulation of Wind System

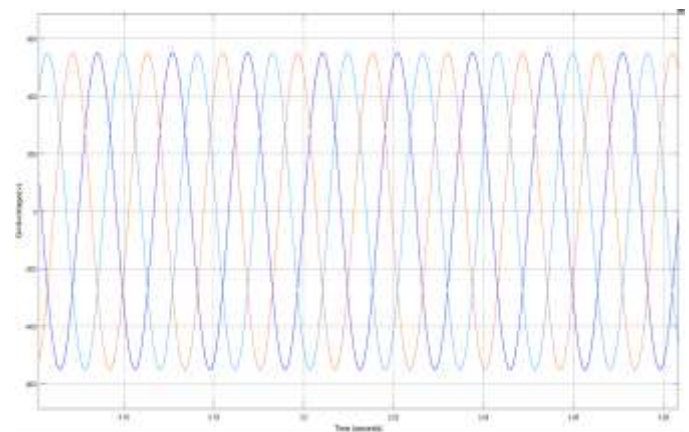


Fig.6. Grid voltages

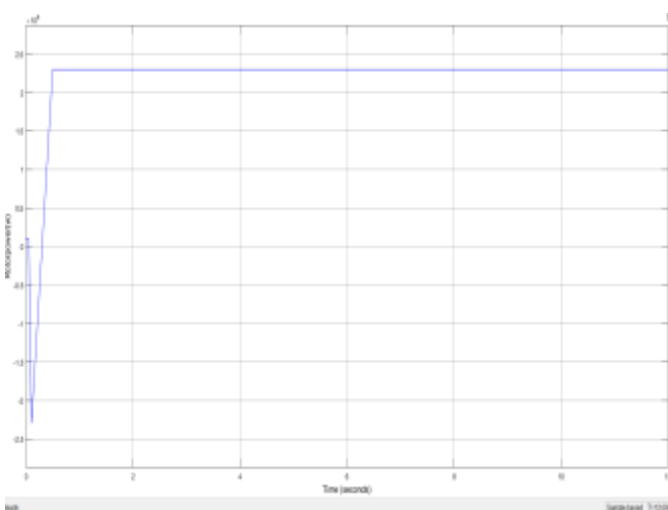


Fig 4. Rotor(Pr) power (W).

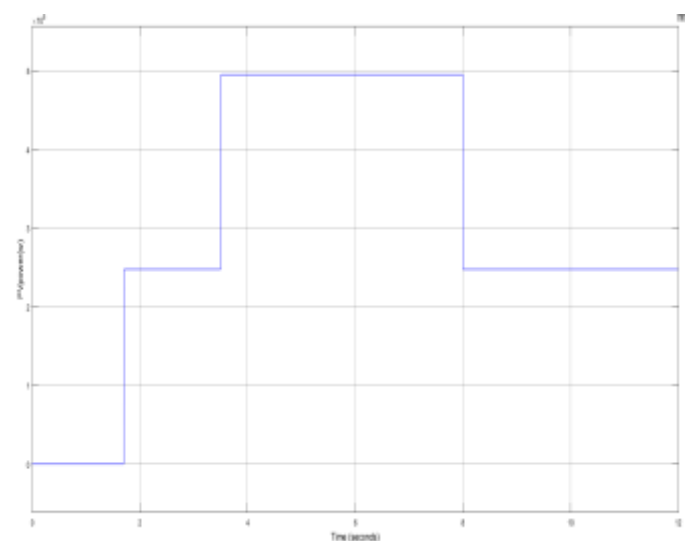


Fig. 7.PV power

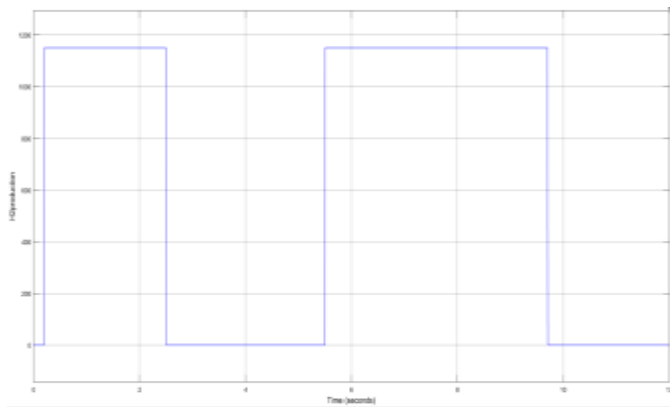


Fig. 8.H2 production (litre).

The DFIG's capability is considered to be 2 MW when the solar system exceeds the GSC rating. The optimal rating for a generator falls within the range of 24 to 31 percent of the GSC and RSC ratings [52]. Consequently, 250 kVA will be allocated for the RSC and 340 kVA for the GSC. The anticipated rating of the PV system is 1.1 MW. To highlight the advantages of the chosen system, its capacity is significantly increased beyond its GSC rating. A 100-Ah Battery Energy Storage System (BESS) linked to this network safeguards the Grid Supply Connection (GSC) from excessive loads. The system comprises a 50 kW fuel cell operating at 625 V and a 35 V electrolyser. Table 1 encompasses the parameters for the DFIG, WT, and GSC. This segment presents and assesses the outcomes of simulating the proposed system across several scenarios. It is thought that solar radiation fluctuates during the day, as illustrated. To avert harm to the photovoltaic system, a circuit breaker and a diode (D1) are incorporated. The circuit breaker activates at the initial moment. The solar irradiance fluctuates over this interval, starting at 0 W/m² for 2–3 seconds, increasing to 1000 W/m² from 3–8 seconds, and subsequently decreasing to 500 W/m² for the remainder of the time. The amount of sunshine that infiltrates a photovoltaic cell affects its ultimate power output. The power and current at the maximum power point tracking (MPPT) are illustrate. The components—BESS, PV System.

5. CONCLUSIONS

This study proposes a hybrid grid-connected system that utilises the minimal number of converters and control loops, integrating fuel cells and electrolysers as energy sources. The characteristics of all system elements and the primary configuration of the suggested system are elucidated. This technical paper addresses the controller design for grid-tied hybrid systems utilising renewable distributed generators (Wind and PV) as the

primary source, BESS as the secondary source, and FC with Electrolyser as the tertiary source. Removing the PV converter from the suggested hybrid system enhances the cost-effectiveness of integrating PV technology. To govern the intended system, power management is employed to enhance the allocation of power among the different sources. GSC enhances PV power efficiency and reintegrates it into the grid. The electricity produced by wind and photovoltaic sources remains unaffected by their variability when battery energy storage systems are synchronised with fuel cells and electrolysers. An electrolyser generates hydrogen from excess energy produced by renewable distributed generation. In adverse weather conditions that hinder adequate power production, FC utilises this hydrogen. We suggest the implementation of a power management system to align with the demand profile, avert overcharging of the BESS, and mitigate the fluctuations and unpredictability of wind and photovoltaic energy. This method guarantees a consistent power supply and uninterrupted services. Integrating fuel cells with an electrolyser into a hybrid grid-connected system reliant on wind, photovoltaic, and battery energy storage systems has led to a significant enhancement. Improvements have been observed in power management, monitoring of the DC link voltage, and maximum power point (MPP) of photovoltaic power from the grid-side converter (GSC). The proposed hybrid grid-connected system may be improved through the implementation of nonlinear controllers, which are more adept at managing the nonlinear characteristics present in the wind, fuel cell, electrolyser, and BESS. An algorithm for power management utilising artificial intelligence can also be implemented.

REFERENCES

- [1] J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galván, R. C. PortilloGuisado, M. M. Prats, J. I. León, and N. Moreno-Alfonso, "Power-electronic systems for the grid integration of renewable energysources: A survey," *IEEE Trans. Ind. Electron.*, vol. 53, no. 4, pp. 1002–1016, Jun. 2006.
- [2] H. HassanzadehFard, F. Tooryan, E. R. Collins, S. Jin, and B. Ramezani, "Design and optimum energy management of a hybrid renewable energysystem based on efficient various hydrogen production," *Int. J. HydrogenEnergy*, vol. 45, no. 55, pp. 30113–30128, Nov. 2020.
- [3] M. Xie, M. M. Gulzar, H. Tehreem, M. Y. Javed, and S. T. H. Rizvi, "Automatic voltage regulation of grid connected photovoltaic system using Lyapunov based sliding mode controller: A

finite—Time approach,” *Int.J. Control, Autom. Syst.*, vol. 18, no. 6, pp. 1550–1560, Jun. 2020.

[4] F. U. Khan, M. M. Gulzar, D. Sibtain, H. M. Usman, and A. Hayat, “Variable step size fractional incremental conductance for MPPT underchanging atmospheric conditions,” *Int. J. Numer. Model., Electron. Netw., Devices Fields*, vol. 33, no. 6, p. e2765, Nov. 2020.

[5] K. A. Khan and M. Khalid, “Improving the transient response of hybridenergy storage system for voltage stability in DC microgrids using anautonomous control strategy,” *IEEE Access*, vol. 9, pp. 10460–10472, 2021.

[6] J. Yao, H. Li, Y. Liao, and Z. Chen, “An improved control strategy oflimiting the DC-link voltage fluctuation for a doubly fed induction windgenerator,” *IEEE Trans. Power Electron.*, vol. 23, no. 3, pp. 1205–1213, May 2008.

[7] B. Benlahbib, N. Bouarroudj, S. Mekhilef, D. Abdeldjalil, T. Abdelkrim, F. Bouchafaa, and A. Lakhdari, “Experimental investigation of power management and control of a PV/wind/fuel cell/battery hybrid energy system microgrid,” *Int. J. Hydrogen Energy*, vol. 45, no. 53, pp. 29110–29122, Oct. 2020.